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GENOTYPIC DIFFERENCES IN COTTON ROOT PENETRATION OF A COMPACTED SUBSOIL LAYER

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Abstract

Roots able to penetrate through compacted subsoil might result in better use of soil water. This study was conducted to determine whether roots of cotton (*Gossypium hirsutum* L.) genotypes differ in ability to penetrate through compacted soil and, if so, to develop a system for early identification of superior rooting. Sixteen genotypes were compared without irrigation in Norfolk loamy sand (fine-loamy siliceous, thermic Typic Kandiudult) overlying a compacted subsoil layer near Florence, SC. Some remained turgid, while others wilted. Roots of the turgid genotypes penetrated the compacted layer, whereas few roots of the wilted genotypes did. One line that remained turgid and one that wilted in the field were then studied over artificially compacted soil cores. Roots of the turgid (but not the wilted) genotype penetrated bulk densities of 1.4 g cm^{-3}. Artificially compacted cores can provide a tool to evaluate genotypes for root penetration as an early part of cultivar development for sandy soils that overlie compacted subsoil.

SOILS of the southeastern Coastal Plain of the USA are sandy and often overlie a compacted layer of subsoil. The combination of erratic rainfall patterns, sandy soils with low water-holding capacity, and the compacted layer of subsoil contributes to dependence on irrigation or a need for disruption of the subsoil layer to increase the rooting zone. Although expensive in time and energy, mechanical disruption can increase the root zone and increase crop yields (Box and Langdale, 1984; Camp et al., 1984). However, the compacted layer often forms again within a few years (Threadgill, 1982; Busscher et al., 1986).

In the summer of 1985, we observed numerous fields on the southeastern Coastal Plain in which nonirrigated crop plants wilted severely while an occasional weed plant remained turgid and appeared to be growing well in the same field. Examination of roots revealed that the turgid weed plants penetrated the compacted layer of subsoil, whereas most roots of the wilted crop plants remained above the compacted layer.

Genetic improvement of rooting characteristics of crop plants offers an intriguing challenge. A modernistic approach might involve identification of the desired genes in a weed plant, and transfer of the genes via biotechnological approaches to crop plants. An alternative approach would be to evaluate existing genotypes of the crop plants to determine whether some have retained ancestral genes for superior root penetration of compacted layers of subsoil. Our objective was to determine whether genotypic differences exist in the ability of cotton roots to penetrate a layer of compacted subsoil and, if differences exist, to develop a system to evaluate genotypes for root penetration as an early part of cultivar development.

Materials and Methods

Cotton genotypes were selected from the USDA Cotton Genetic Program at the Clemson University Pee Dee Research and Education Center near Florence, SC. We selected

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genotypes with a range of ancestry, including some known to differ in responsiveness to irrigation (T.W. Culp, 1984, personal communication). The genotypes were first examined in a nonirrigated field over a naturally compacted subsoil layer, and then two of the lines were selected and grown in a controlled environment over artificially compacted soil cores with a range of penetration resistances to the growing roots.

Field Observations

Single 10-m rows of 16 genotypes were grown in a field of Norfolk loamy sand that overlies a naturally compacted subsoil layer at the Coastal Plains Soil and Water Conservation Research Center near Florence, SC. The upper surface of the compacted layer was ≈20 cm below the soil surface. Rows were 1 m apart. Seeds were sown on 18 July 1986, and rainfall was adequate for high germination and early growth. The mid-July planting date was selected to increase the probability that plants would suffer water stress during the hot days of summer if the roots were unable to penetrate the compacted soil layer and extend into moist soil. No irrigation water was supplied. A severe drought occurred after the plants were ≈ 25 cm tall. This provided an opportunity to compare field growth of the various genetic lines without irrigation over a compacted subsoil layer. The plants were evaluated for shoot and root characteristics 80 d after planting.

Controlled Environment

One genotype that remained turgid (PD-1) and one that wilted severely (PD-695) in the field test were used in a controlled environment study. Individual plants were grown in uncompacted soil over an artificially compacted 2.5-cm thick soil core, which was positioned over more of the uncompacted soil (Fig. 1). This arrangement allowed continued growth of roots that penetrated through the compacted cores.

Norfolk loamy sand collected adjacent to the field study was air dried, sieved to remove roots and soil aggregates larger than 2 mm in diam., autoclaved at 1 kg cm^{-2} for 15 min to kill weed seeds, cooled, and thoroughly mixed with enough water to give 51 g kg^{-1} moisture, which is field capacity for this sandy loam soil. After adjusting the moisture content, soils were kept in plastic bags to avoid drying. Soil cores (2.5 cm thick and 7.5 cm diam.) were compacted to bulk densities of 1.0, 1.4, and 1.7 g cm^{-3}. Extra cores were compacted and used to obtain penetration resistances using a 5-mm diam. flat-tipped penetrometer (Mirreh and Ketcheson, 1972). Penetration resistances of the 1.0, 1.4, and 1.7 bulk density cores at 51 g kg^{-1} moisture were 0.026, 0.589, and 2.450 MPa, respectively. The 7.5-cm high, 7.5-cm diam. cylinders (which held 330 cm^3 of uncompacted soil) were taped above the 2.5-cm high cylinders containing the compacted cores, and these assemblies were partially embedded in 500 cm^3 of soil in 13.5-cm diam. containers (Fig. 1). Four seeds were placed in the soil of the top compartment, and a transparent plastic bag was placed over each assembly to serve as a barrier to water loss from the soil surface. When seedlings emerged, they were thinned to one per container. A small slit was made in the plastic cover for the seedling. Transparent tape was then used to reduce the size of the opening around the seedling stem. There were eight identical assemblies for each of the two genotypes for each of the three soil bulk densities. They were placed in a growth chamber without additional water, and grown until plants attained permanent wilt. Plants received 18-h d from cool-white fluorescent lamps about ≈500 $\mu mol\ m^{-2}\ s^{-1}$ and 25 °C day and night temperatures.

The date that each plant reached permanent wilt was recorded. Each assembly was then dismantled by first raising the combined upper cylinder and compacted core to determine whether any roots had penetrated through the core. The upper cylinder was then separated from the compacted core to determine if roots had entered the core. Soil from each of the three zones was sieved, and roots were spread on a sheet of paper and identified as above, within, and below the core. They were covered with clear plastic to keep materials in place, and photocopied on an office photocopier for later detailed measurements. Weights of roots were obtained after photocopying and freeze drying.

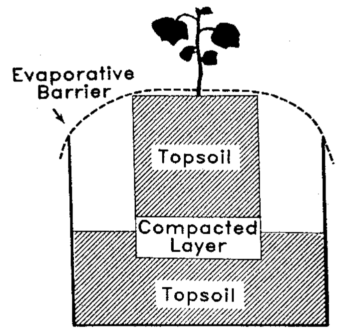

Fig. 1. Diagram of assembly used to study cotton root penetration of artificially compacted soil cores.

Results and Discussion

Field Observations

Cotton cultivars and breeding lines differed in amount of wilting when grown without irrigation in field plots of sandy soil over a naturally-compacted subsoil layer during the extended drought of 1986. Several of the genotypes remained turgid, while others wilted severely. Turgid plants were tall and dark green, with numerous bolls. Severely wilted plants were short, with very few bolls. Wide differences existed among (but not within) the genetic lines. Roots of genotypes that remained turgid had penetrated the compacted subsoil layer, whereas those that wilted severely had little root penetration of the compacted layer. The differences among genotypes in the amount of wilting in the nonirrigated field study suggested a need to investigate possible genotypic differences in root penetration of artificially compacted soil cores under controlled conditions. The rationale was that if cotton genotypes that either wilt or remain turgid in the field also differ in ability to penetrate the artificially compacted soil cores, such a system might be useful to identify superior genotypes during early stages of cultivar development.

Artificially Compacted Soil Cores

Genotypes that wilted (PD-695) or remained turgid (PD-1) in the field study differed in response to bulk density (and penetration resistance) of artificially compacted soil cores in a controlled environment (Table 1). With the soil moisture initially at field capacity, roots of 75% of the PD-1 plants penetrated through the 1.4 g cm^{-3} bulk density cores, whereas none of the PD-695 roots did. As expected, no roots of either genotypes entered the 1.7 g cm^{-3} bulk density cores, which had penetration resistances of ≈2.45 MPa. On the other hand, roots of all plants of both genotypes penetrated on the 1.0 g cm^{-3} bulk density cores, which had penetration resistances of only 0.026 MPa. Plants

Table 1. Characteristics of PD-1 and PD-695 cotton seedlings grown in a controlled environment from seeding to permanent wilt in Norfolk loamy sand over artifically compacted soil cores (as shown in Fig. 1) with bulk densities of 1.0, 1.4, and 1.7 g cm^{-3}.

Plant characteristic	Soil core bulk density and cotton genotypes						LSD	
	1.0†		1.4		1.7			
	PD-1	PD-695	PD-1	PD-695	PD-1	PD-695	0.1	0.05
Days to permanent wilt	20	19	17	14	14	14	1	2
Root dry wt., mg plant^{-1}								
Above core	–	–	29	31	35	28	NS	NS
Within core	–	–	3	2	0	0	–	–
Below core	–	–	23	0	0	0	–	–
Total	49	37	55	33	35	28	11	13
Root lengths, m plant^{-1}								
Above core	–	–	1.46	1.38	1.55	1.40	NS	NS
Within core	–	–	0.06	0.03	0.00	0.00	–	–
Below core	–	–	0.55	0.00	0.00	0.00	–	–
Total	2.01	1.75	2.07	1.41	1.55	1.40	0.34	0.40
Weight/root length, mg (dry wt.) m^{-1}	24	21	27	23	23	20	2	3

† Roots of both genotypes penetrated the 1.0 cores and distributed throughout the entire soil volume. There was no attempt to separate roots according zones designated above, within, and below the cores.

whose roots did not penetrate the soil cores exhausted available soil moisture and reached permanent wilt sooner than plants whose roots were not blocked by the compacted cores. The PD-1 plants developed greater root biomass and cumulative root lengths per plant within each soil bulk density. This pattern was most evident when PD-1 penetrated the compacted layer (bulk density of 1.4 g cm^{-3}) and obtained a larger rooting volume.

The field and controlled environment observations demonstrated that cotton (and presumably other crop species) genotypes can differ in root penetration of compacted soils. Consequently, cotton genetic lines that are equally productive under ideal nutrient and moisture conditions might differ significantly when grown on soils with increased root penetration resistance, such as is associated with a compacted subsoil layer below sandy surface soil on the southeastern Coastal Plain.

We conclude that an evaluation system for root penetrability should be part of the selection criteria during early stages in development of cultivars that are likely to be grown in sandy soils that overlie a compacted subsoil layer. In a practical application, a larger volume of moist soil below the compacted core (see Fig. 1) would allow a longer growth period and easier identification of plants whose roots penetrated the compacted soil core. This approach might lead to cultivars with improved ability to penetrate compacted soils and decrease the need for frequent irrigations. A decrease in irrigation frequency might also decrease the probability of groundwater contamination associated with movement of nutrients by irrigation water through the sandy loam surface soil.

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